Measuring the Neutrino Mass Hierarchy with PINGU

The Precision IceCube Next Generation Upgrade (PINGU) [1] will be proposed as a new detector to measure the neutrino mass hierarchy (NMH) with atmospheric neutrinos [2,3]. Conceived as an in-fill array for IceCube at South Pole Station, Antarctica, PINGU will consist of a few dozen new strings, each with 50–100 digital optical modules (DOMs) very similar to those currently deployed in IceCube. Located within and around existing IceCube/DeepCore DOMs, PINGU will have a large fiducial volume detector of O(10 MTon) and a neutrino energy threshold of roughly a few GeV. Such a detector is expected to accumulate O(25k) triggered, contained neutrino events* each year between 5 and 20 GeV, a region with pronounced sensitivity to the NMH. Preliminary Monte Carlo studies indicate that energy and angular resolutions necessary to observe a statistically significant NMH effect in the zenith angle-energy space are likely achievable. Studies are ongoing to determine whether or not the required neutrino efficiency, flavor purity, background rejection and systematics are also achievable in a detector of this design. Any detector with sensitivity to the NMH using atmospheric neutrinos will also have sensitivity to a variety of other important physics. This includes high statistics measurements of ν_μ disappearance and ν_τ appearance, possible determination of the maximal nature of θ_{23}, and extension of the sensitivity for indirect detection of low mass WIMP dark matter. Such a detector could also detect parametric neutrino oscillations for the first time [4] and provide unique, new data for the measurement of geological properties of the earth's core and mantle.

PINGU is designed with straightforward integration into IceCube's online and offline systems in mind, and will thus benefit considerably from existing infrastructure. As an extension of the IceCube project, existing software systems will be leveraged to minimize the additional effort needed to acquire, transfer, store, process and analyze PINGU data. Further, as successfully demonstrated by DeepCore [5,6,7], the surrounding IceCube DOMs will provide a nearly hermetic real-time veto against cosmic ray muons, the primary background of all PINGU physics channels.

The physics goals of PINGU, focused in a narrow energy range, enable a number of simplifications and enhancements relative to IceCube. The low energy neutrinos of interest will typically deposit single or few photoelectron signals in the DOMs. Signals with such low dynamic range can be digitized and processed *in situ* with commercial electronics and an attendant reduction in on-board complexity. The IceCube Enhanced Hot Water Drill (EHWD) is a robust and fully tested system, and the necessary refurbishment or rebuilding of parts is well understood. Additionally, modest planned enhancements are expected to further increase the clarity of the refrozen drill-hole water. The PINGU physics goals also demand improved calibration techniques at low light levels, and work is ongoing to design remotely-controllable, *in situ* light sources akin to the LEDs currently placed in each deployed IceCube DOM. Generally speaking, the wealth of experience gained from the successful deployment of 86 IceCube strings renders the most important risk factors small and well understood.

Assuming approval of a proposal submitted in 2013, six PINGU strings could be deployed in early 2016 followed by about fifteen strings annually in subsequent years, with a potential initial measurement of the NMH as early as 2020. The cost is very roughly estimated to include a \$10M fixed cost for the EHWD and \$1.25M per deployed string, based on costs to produce and deploy IceCube strings, including logistics but without contingency and escalation factors.

With an eye towards future detectors beyond PINGU, the co-deployment of a few specialized R&D optical modules is planned. The goal of this R&D effort is to investigate the potential to reconstruct fragments of Cherenkov rings produced by events with GeV energies in the deep, clear ice. This could potentially provide a path to a megaton-scale detector with sensitivity to proton decay, and supernova neutrino bursts at semi-annual frequency.

*Contained events are from ν_μ and anti-ν_μ interactions that deposit Cherenkov photons in at least 20 DOMs and originate within 75 m of the center of a detector with active instrumentation in a cylindrical volume of 125 m radius and 250 m height.

References

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